Study of High Efficient Peniotron(高効率ペニオトロンに関する研究)

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論　文　内　容　要　旨

CHAPTER 1　INTRODUCTION TO THE FAST WAVE DEVICES

Recently, there has been a great deal of interest in the development of efficient sources of microwave to submillimeter wave, capable of operating at a power level of order of megawatts. Intensive researches have been mainly focused on two class of devices, free electron laser(FEL) and cyclotron resonance maser.

The interaction space of the cyclotron fast wave device is immersed in a homogenous magnetic field and contains electrons rotating around the axis of the magnetic field at the cyclotron frequency. Gyrotron and Peniotron are representative examples of such devices.

We proposed a new type of peniotrons called the high efficient TE_{11} rectangular peniotron in 1985. The new type has advantages of higher efficiency and higher power capability than those of the original peniotrons. The result of large signal interaction calculation showed a total efficiency of 79% in the fundamental mode of operation.

CHAPTER 2 THE BASIC PHYSICS OF THE HIGH EFFICIENT PENIOTRON

The principle of the TE_{11} peniotron is based on the interaction between an electromagnetic wave propagating in a TE_{11} rectangular waveguide and a thin hollow electron beam rotating around the field lines of an applied dc magnetic field at a cyclotron angular frequency. The interaction principle is the same as the original peniotron and for simplicity we will discribe the original peniotron. Two typical electron orbits are usually considered; first, the orbits of an electron initially accelerated by the rf electric field and second, initially decelerated. In the case of the former, the electron's speed increases at first and hence its orbit becomes larger. When the electron has moved half an orbit and the electric field has gone a complete cycle, the electron will be decelerated in the left side. However, the electron will be closer to the ridges than before and, thus, the electron's deceleration will be greater than its previous accelertation, resulting in an overall deceleration for the orbit. The electron will continue to spiral into the smaller orbits. In the later case, by the same argument, the initially decelerated electron will spiral into smaller orbits. Both the groups supply their kinetic energy to the electromagnetic wave.

CHAPTER 3 Analytical model, simulation results and discussions

We have analysed the operational characteristics of the high efficient peniotron for the fundamental mode operation of using some computer simulations.

Throughout the analyses the cavity conditions are fixed as follows:

Type : Short end half wavelengh TE_{11}

Size : 21×21 (cross–section)×150 (lengh) mm

Q_{ext} : 2000

Resonant Frequency: 10 GHz

It is also assumed that the dc magnetic field is uniform throughout the cavity region. Figure 3.1 shows the energy conversion efficiency as a function of the output power P_0 for the respective accelerating voltage. As shown in the figure, the highest conversion efficiencies for all of these accelerating voltage are about the same and more than 79% . This value corresponds to over than 99% in terms of the transvers efficiency.

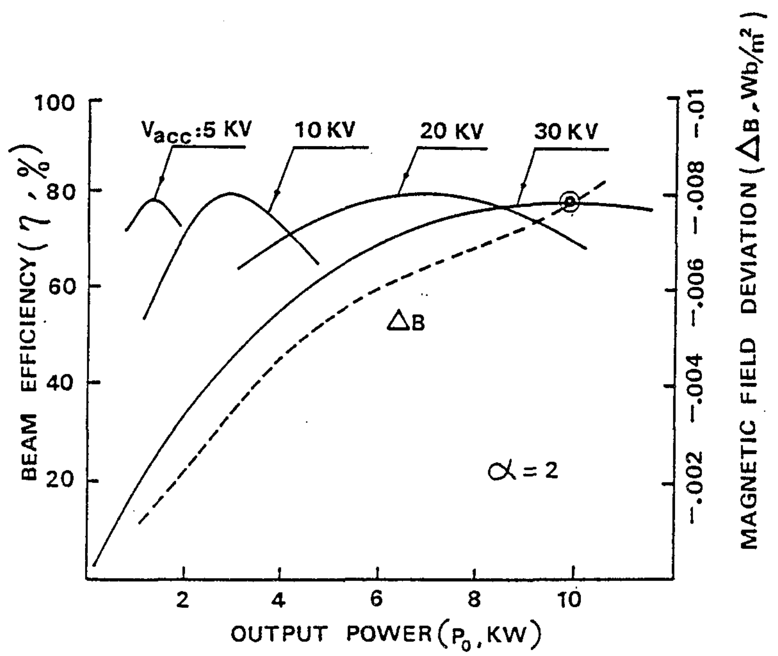

Figure 3.1 The conversion efficiency as a function of tthe out-put power for the different accelerating voltage. ΔB expresses a magnetic field deviation from the resonant condition for v_{acc} =30 kv.

CHAPTER 4 ELECTRON GUN DESIGN

The emitting area of the electron gun is a circular cathode with outer and inner diameters of 13.25 mm and 12.75 mm respectively. The hollow non-rotating electron beam is accelerated between the cathode and anode region and flows into the forming magnetic circuit.

The forming magnetic circuit or, as we call it the gun magnetic circuit consists of three solenoids with three pole pieces forming two cusped fields. The non rotating hollow electron beam emitted from the circular cathode is made to rotate, by passing through the second cusped field.

When the electron beam is progressing inside the drift tube it is compressed to its final value of designed diameter.

CAVITY DESIGN CONSIDERATION

For the cold test experiments, a model of the cavity was constructed and studied for the following parts;

a) Measurement of the mode structure,

b) Determination of the cavity Q,

c) Resonant frequency spectrum of the cavity.

R. F. WINDOW AND BEAM COLLECTOR DESIGN

Since the gun and cavity assembly are working in vacuum, the output port of the tube should be closed. For this reason a rf window must be used but it is restricted to have characteristics of low loss and reflection for the transmitted microwave power. We have studied alumina as a rf window under two main subjects:

1. Dielectric effect of the alumina in the waveguide.
2. Design consideration for metal/ceramic joint.

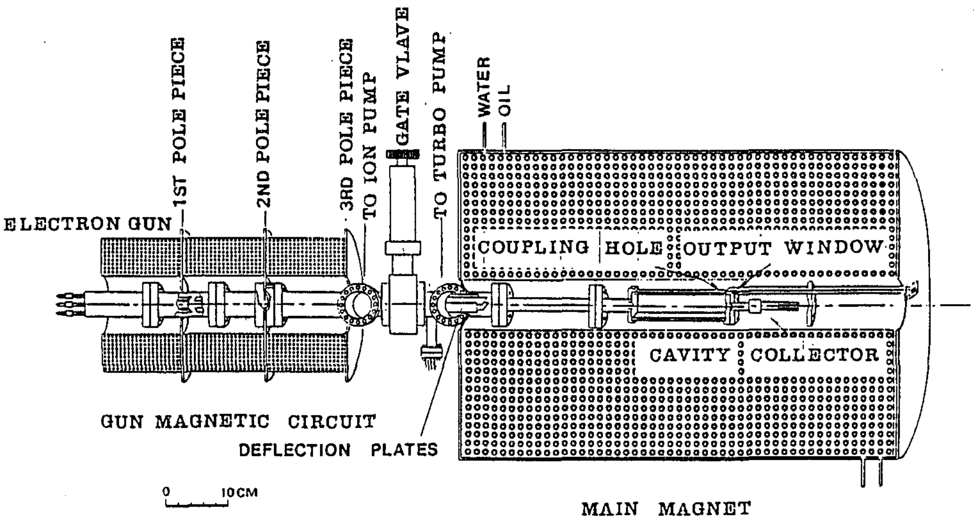

Figure 4.1 Overall design layout of TE_{11} peniotron oscillator

CHAPTER 5 EXPERIMENTAL RESULTS

We examined the emission characteristics of the electron gun and observed the shape of electron beam by putting a fluorescent screen behind the cusp field.

By changing the dc magnetic field intensity, many frequency lines of oscillation corresponding to the resonant spectrum of the longitudinal higher order modes of TE_{10n} to TE_{11n} were observed.

Figure 5.1 shows the output power and efficiency for different values of the collector current at the accelerating voltage of 30 kV and the oscillation frequency of 10 GHz. At each point, the dc magnetic field intensity is adjusted to produce the highest output power. As shown in the figure the total efficiency including the loss in the cavity reaches to 30%. Considering the unloaded Q value of 8000 and the loaded Q of 2000, the electronic efficiency exceeds more than 50%.

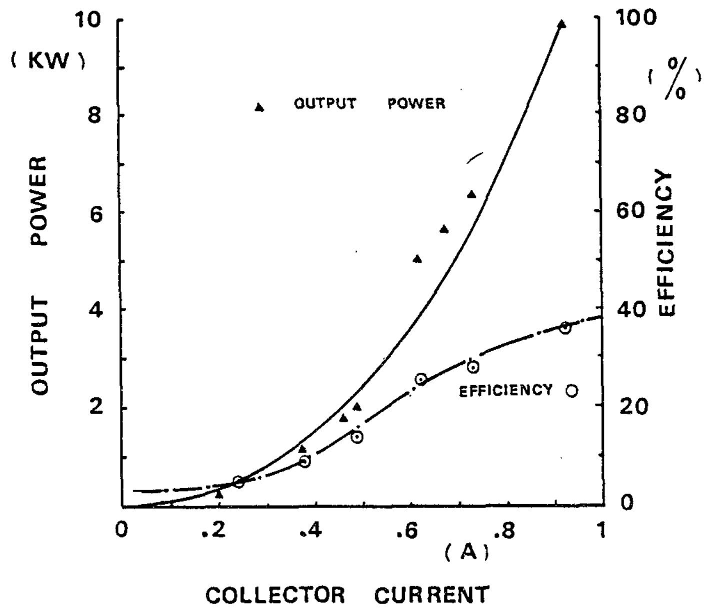

Figure 5.1 Output power and efficiency versus collector current.

CHAPTER 6 CONCLUSION

We examined the first test tube as an oscillator operating in the fandamental mode at 10 GHz. We could obtained a fairly high electronic efficiency of 50% at 10 kW output power and confirm the promising performance of this tube.

The theoretical and numerical model and practical design considerations developed in the previous chapters serve as a basis for future work.

Future improvement in performance can be expected from the following suggestions;

a. Some improvement of the beam quality should be needed by extending our previous study of the electron gun design, and considering the space charges effect in electron gun simulation programs.
b. Providing a depressed collector potential to retrieve the axial component of the beam energy, a higher efficiency should be obtained.

審　査　結　果　の　要　旨

近年，核融合プラズマの加熱，高解像度レーダ等に使用する大電力ミリ波光源の開発を目的として，ジャイロトロンやペニオトロンの研究が非常に活発化してきている。これらは共に，一様磁界の軸に沿い回転しながら進む電子流と電磁波との相互作用を利用した電子管，いわゆるサイクロトロン高速波管の一種であるが，動作原理と構造上の差異により，前者は出力電力レベルで，後者は高効率性において互に相手を凌駕する特性をもっている。

著者は，後者の出力電力レベルを前者のそれに近付けるべく，新たに考案された改良形ペニオトロンについて理論的，実験的研究を行ってきた。本論文はその研究の成果をまとめたもので，全文6章より成る。

第1章は緒言である。

第2章では，ペニオトロンの動作原理を説明すると共に，従来形のものでその出力電力を制限する要因，並びに，それらを除去する事を意図して考案された改良形におけるペニオトロン動作について述べている。

第3章では，改良形ペニオトロンの動作特性を求める解析モデル，動作シミュレーションの結果について述べている。ここで，この形の動作効率は従来形のものと比べても非常に高く，電位降下形電子集電極を使用すれば100％に近い高効率動作も可能である事，又，その高効率となる物理像を明らかにしているが，これらは高く評価すべき成果である。

第4章では，前章の結果を実験的に検証するため，発振周波数10 GHz，出力10 K Wに設定して試作した実験管各部の設計と製作法，並びに，実験装置の構成について述べている。

第5章はこの実験管による動作実験の結果を述べたものである。実験は，先ず電子銃の動作について行い，目的とする回転電子流の得られる事を確認している。次いで，発振動作の実験を行っているが，その第1段階での出力は数 100W程度で設計値を大巾に下回り，その原因を検討し動作に重要な三つの軸の一致，即ち，回転電子流を形成するためのカスプ磁界，相互作用用に必要な主磁界と実験管との三つの軸の一致が得られていないのが原因である事を見出している。軸の再調整を行った後，出力は設計値の10 K Wに達し，更に，動作効率は設計値の80％には到達しえなかったが50％を越え，この改良形ペニオトロンの高効率性を示すに十分な結果を得ている。

第6章は結言である。

以上要するに本研究は，改良形ペニオトロンについて理論的，実験的研究を行い，その優れた高効率性と大出力動作の可能性とを示し，この管の高効率，大出力ミリ波光源としての将来性に明るい見通しを与えたもので，電子工学に寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。